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Introduce a Novel Spot-scanning Proton Arc (SPArc) Optimization algorithm for Synchrotron-Accelerator-based Proton Therapy System (PTS)

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Objectives

SPArc has drawn significant interest from the particle therapy community. However, all existing SPArc optimization algorithms are designed only for cyclotron accelerators ($PTS_{-cyclotron}$) rather than synchrotron-accelerator-based Proton Therapy Systems with the Single Energy Extraction (SEE) technique ($PTS_{-synchrotron-SEE}$). The $PTS_{-synchroton-SEE}$ delivers a bunch of proton particles through each pill. The remaining proton particles of that specific energy layer will be discarded if not used, which could result in a significantly prolonged treatment delivery. Thus, this study aims to develop the first SPArc optimization algorithm based on the Dynamic Programming ($SPArc_{-DP}$), to improve the proton arc treatment delivery efficiency for $PTS_{-synchrotron-SEE}$.

Methods

Dynamic Programming, initially designed for combinational optimizations in fields of bioinformatics, finance and scheduling, was introduced to optimize the energy layer and MU distribution based on the features of the $PTS_{-synchroton-SEE}$. It started from a plan generated via the original SPArc algorithm ($SPArc_{-original}$). Based on the maximum charges per extraction, it iteratively merges the adjacent energy layers into the same energy layer while ensuring the plan quality. Thus, it effectively reduces the unnecessary cycling from the $PTS_{-synchroton-SEE}$ by maximizing the utilization rate of each spill. Four representative disease sites are selected for testing purposes, including liver, unilateral HN, lung, and prostate cancers. The $SPArc_{-original}$ plans are used as benchmarks. Dosimetric metrics, including target dose conformity index (CI), target coverage, and OARs sparing, were evaluated, and the total number of cycles, utilization rate of each spill, and treatment delivery time(*TDT*) were simulated and compared between $SPArc_{-original}$ and $SPArc_{-DP}$.

Results

With a similar plan quality, the $SPArc_{-DP}$ plans reduced the number of acceleration spills from 154±22 to 54±15 on average compared to the $SPArc_{-original}$ plans. These improvements effectively reduced treatment delivery time by 210.47 seconds ± 40.93 seconds (approximately 57% ± 6%) compared to the $SPArc_{-original}$ plans.

Conclusions

The study introduced the first SPArc optimization algorithm for the $PTS_{-synchrotron-SEE}$. With a similar plan quality, the treatment delivery time could be significantly reduced on various disease sites, which paves the roadmap to implement the SPArc technique.

Figure 1: The plan quality and DVH comparison between $SPArc_{-original}$ and $SPArc_{-DP}$ plan of unilateral head & neck cancer. (A) $SPArc_{-original}$;(B) $SPArc_{-DP}$; (C)DVH shows the dosimetric difference between $SPArc_{-original}$ (solid line) and $SPArc_{-DP}$ (dashed line) ;(D) dose difference between $SPArc_{-original}$ and $SPArc_{-DP}$ plan.

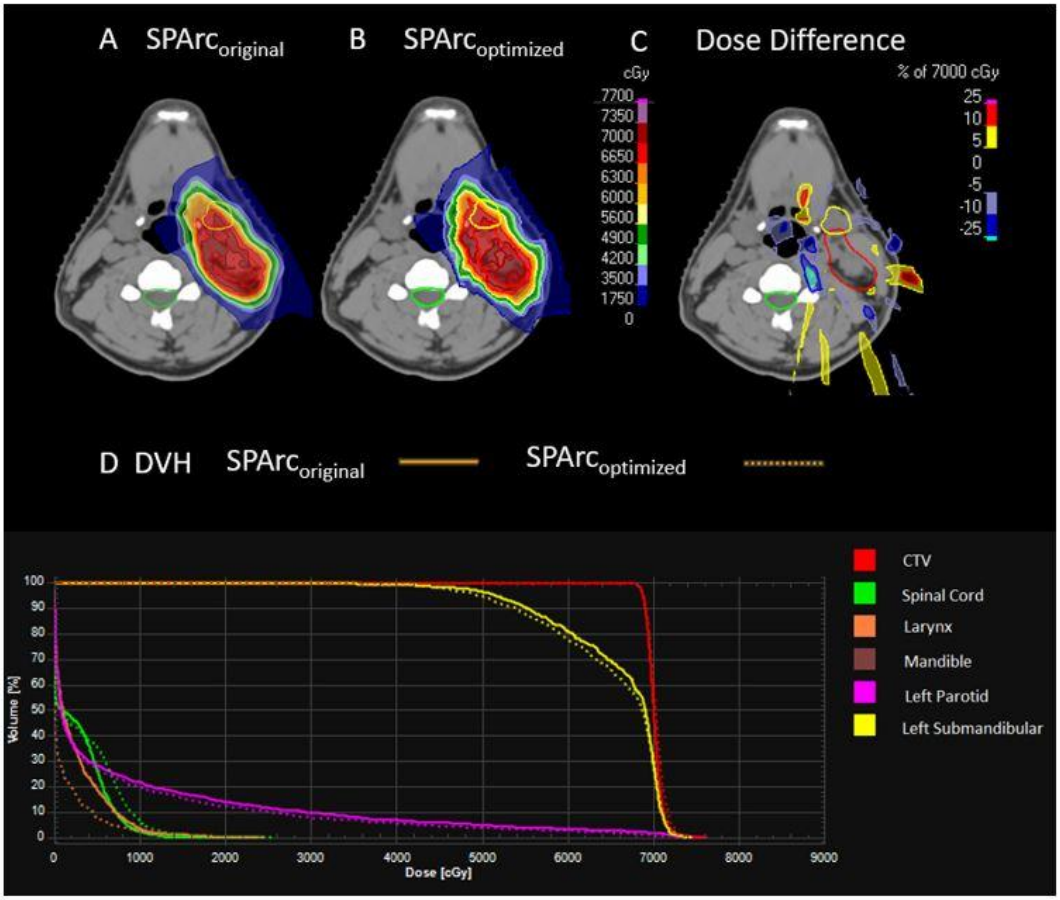

Figure 2: The cross-comparison of duty cycle by MU efficiency (A) and extraction time efficiency (B) between $SPArc_{original}$ and $SPArc_{DP}$ for liver, HN, lung, and prostate cancer cases.